HEALTH STUDIES ON ROCKY FLATS

HISTORICAL PUBLIC EXPOSURES STUDIES

Phase II:
Toxicity Assessment and Risk Characterization

Technical Memorandum

903 Area Dosimetry Spreadsheet: How does it work and what does it tell us?

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INTRODUCTION

The Rocky Flats Plant (RFP) historically existed as a complex that machined plutonium for weapons material beginning in the 1950's. This machining left plutonium contaminated oil as a by-product, for which no disposal option existed. The waste was instead stored in steel barrels at an outdoor location east of the plant, now known as the 903 area. Gradual chemical corrosion of the barrels resulted in leaks of plutonium to the ground, contaminating the soil and making that contamination available for transport offsite by environmental conditions. For a complete summary of the history of the 903 area, refer to the *Radiological Assessments Corporation (RAC)* Rocky Flats Plant 903 Area Plutonium Source Term Development Report (Meyer, et al., 1996).

Since plutonium has been recognized to be a hazard to humans when internalized, the offsite movement of the material by wind events is especially hazardous. The resuspension of plutonium into air and the inhalation of that air is of significant concern from a human dose perspective. Consideration also needs to be given to the dose that would be delivered to a person ingesting plutonium contaminated soil.

In order to deal with these questions and a number of other concerns that have arisen during the Phase II study being conducted by *RAC*, an interactive tool has been developed to make calculation of dose from a source like the 903 area simple to follow and understand. This 903 area dosimetry spreadsheet also compares a number of different aspects of dose that become a part of the different scenarios considered in a dose calculation. The purpose of this exercise is to attempt to rule out potential pathways that don't contribute significantly to dose or to eliminate unnecessary use of the scenario concept on details that are not representative of a typical population dose.

SPREADSHEET LAYOUT

Meteorological data

The spreadsheet uses wind and weather data that was collected at the Jefferson County (JeffCo) airport during a time period of interest, in this case, the month of January 1969 (U.S. Dept. of Commerce, 1969). The data includes Julian date (or day of the year in numerical form, from 1-365), the time of the day (in military time), the wind speed (m/s), wind direction (direction the wind comes from in degrees from north), the insolation class (a function of degree of cloud cover and solar effects), the stability class (a function of cloud cover, wind conditions, and ceiling height), whether the time of day is designated as day or night, the gust speed (m/s), and the minutes per hour of interest that gusts occurred. In its current form, the spreadsheet uses a constant value for the minutes per hour gusty, but this can easily be altered for any hour by simply changing the value in the appropriate cell.

Resuspension code

The term used to describe the mechanism for particles located on the ground becoming airborne is called resuspension. Wind-driven resuspension is of primary concern for this study, so an algorithm which accurately describes the resuspended source of particles available for downwind transport above the contaminated area is needed.

Resuspension has long been studied as a sub-topic of the larger research interest of erosion. Resuspension, however, deals with particles small enough and light enough to remain airborne for some period, where erosion is concerned with the larger problem of total soil removal from an area by any mechanism. An obstacle to predicting resuspension is that it is largely dependent on the makeup of the surface of interest and the wind and weather conditions present. The best resuspension predictor studies for any set of conditions would be conducted under identical conditions to those present during the period to be modeled. In the absence of a study with the exact conditions reproduced, one must rely on the best science available within the limitations of the information which can be obtained on the area. If limited data is available, it makes little sense to use a complex model that will only serve to increase the uncertainty of the answers, when a simpler model can be used with a higher degree of certainty.

A straightforward approach to resuspension was developed by Porch (Porch, 1979) and made useable with a Hewlett Packard pocket calculator through collaboration with Gifford (Gifford and Porch, 1993). This code, known as GAUS1, has been adapted into a spreadsheet calculation for use here. The calculation is based upon a number of resuspension tracer experiments conducted at various sites as well as actual studies of radioactive particle resuspension, with plutonium in particular, so this code lends itself well to use in this spreadsheet. In addition, the code is very portable and easy to understand. The basic elements of the code have been previously described in a *RAC* Technical Memo (Weber, 1996).

A number of parameters are required as input into this code as described in the following summary.

The soil type can be defined as the best approximation among the four choices of soil available: sand, loam, clay, and snow. In the spreadsheet there is a cell which takes the soil type as an input and returns the appropriate parameter values to all cells which are affected by this choice. These cells include those labeled c1, c2, and Fo. These are cells which describe the powers and multipliers used to determine the frictional velocity of the surface from which the particles will be resuspended.

The area of interest is also an input parameter. The approximate area of the 903 pad is 0.014 km^2. The roughness coefficient is determined by the ground cover, using values of 0.0028 for bare soil cover, 0.0042 for low vegetation, and 0.0052 for high vegetation. The addition of this variable into the calculation is done in a way that is non-intuitive in that source term actually increases with increased vegetative cover. A logical interpretation of the ground cover would have source term decreasing under these conditions, as particles on the ground would be less available to be resuspended due to the interference of the vegetation. But GAUS1 assumes that particles deposited on vegetated ground will actually be MORE available for resuspension since they will be located on leaves and stems and not connected in some way to the soil. This assumption is debatable, but does not become a factor for this calculation since the 903 area consists primarily of bare soil cover, and that value is used exclusively in the calculation.

The GAUS1 code does an effective job of calculating basic resuspension, but it relies on the user being able to determine the surface concentration of suspendible toxic particles. This means that it is necessary to determine not only the total fraction of suspendible material present, but also what portion of those suspendible particles are associated with toxic material, in this case, plutonium. The conservative estimate would involve determining

the total mass of plutonium released to the 903 area and assuming all of that plutonium to be associated with suspendible particles. The particle size distribution at the 903 area has been the subject of numerous studies at various times. No studies of this nature were done during the time period of interest, however, limiting knowledge of the exact conditions under which the pad in its highly contaminated state existed and creating a source of uncertainty. At the time of preparation of this paper, a value for soil contamination had yet to be determined. As a result, the value which appears in the spreadsheet is arbitrary. Since this value is used in the same way in every calculation, using an arbitrary value will have no effect on the relative value of the doses to one another.

One of the powerful aspects of the GAUS1 code is that it deals directly with the effects of wind gusts. Though suspension is primarily wind driven, it is dominated even more exclusively by extremely high wind conditions. The 903 area has been such a focus of concern because of the well-recognized extremes at which wind speeds are frequently measured along Colorado's Front Range. The high wind speeds common at the RFP and actually measured during the time period of greatest concern for the 903 area make resuspension of plutonium not just a possibility, but a probability. GAUS1 takes into account not only the speed of the wind gusts measured during any hour, but also the frequency with which those gusts occur during an hour of interest. A particularly gusty hour would result in a much higher level of resuspension than an hour which saw no gusts at all.

The output of the GAUS1 code is source term, as measured in grams of toxic particles resuspended per second. The source term in the spreadsheet has been calculated both with and without the use of gusts by simply removing the segment of the GAUS1 calculation which deals with gusts. This allows for a simple visual representation of the effect that gusts have on the source term and thus on the dose to a population. For the air dispersion code used in this spreadsheet, the source term needs to appear in units of grams of toxic material resuspended per second per square meter of area covered by the contamination. To do this, the source term is simply divided by the total area subject to contamination.

Air dispersion model

The downwind air concentration is calculated in this sheet with the use of a standard Gaussian Plume model. The one exception to the standard form is that the source in this calculation is an area as opposed to a point source.

The dispersion model is written as a Visual Basic macro called "gaus" which is resident to the spreadsheet. The macro operates in a similar fashion to any function in Excel. It is called by typing an equal sign followed by the name of the function. The function has a parameter list which must follow the name in order for the function to use the appropriate values for calculation of the final air concentration. These parameters in order of input are release rate (g/m^2s), downwind distance (m), crosswind distance (m), receptor height (m), wind speed (m/s), release height (m), mixing height (m), and the length of one side of the area source (m, assuming a square area). The 903 area is not exactly a square, but is rather close, so the average of the lengths of the four sides is used as the length of one side of the square.

In each of the cells which calculates air concentration, the dispersion model macro has already been applied, so the user need not worry about understanding the operation of

Excel functions in any way. The function can be located by using the function wizard and looking under user defined functions for the one entitled "gaus".

The air concentration is calculated at a location defined based upon the wind direction. The wind direction in the meteorological data is given as the direction the wind is coming from in degrees from north. The predominant wind direction at the RFP is coming out of the mountains from the west. In degrees from north as presented in the JeffCo data, this would correspond to an angle of 270 degrees.

The function is written to accept a downwind distance (x) parallel to the wind direction and a crosswind distance (y) perpendicular to the wind direction. If the wind direction were 270 degrees, and the desired location for the air concentration were 100 meters directly east of the plant, the appropriate coordinates for x and y would be 100 and 0, respectively.

Unfortunately, the wind does not always blow in the same direction. In order to determine the dose 100 meters directly east of the plant, it is necessary to determine the x and y components of the vector which designates the wind direction. This is done using Pythagorean's theorem with a constant adjacent side length of 100 meters and one angle of the right triangle determined using the wind direction from the met data.

For application to the air dispersion calculation, the wind directions are separated into 16 different wind sectors, the wind speeds are separated into six different classes, and the stability classes are also separated into six different classes. This allows the setup of a joint probability distribution which makes it possible to determine air concentration in any one of the 16 different sectors based upon the wind speeds given. A complete summary explaining this technique appears as Appendix A.

The air concentration has also been determined at a distance of 1000 meters from the 903 area. The calculations which show the difference that directional location makes in determining dose can be assumed to show a similar relationship to one another as that which will be seen over the entire time span that will be modeled for the 903 area. This is because the wind speeds and wind directions used in this calculation actually came from a location close to the site, and the conditions observed during January 1969 are a good representation of many of the extremes which can be seen at the plant.

Radiotoxicity of soil

Since the source term is given in units of grams of toxic particles released per second, it is necessary to translate that value into a toxic particle activity. Based upon knowledge of the plutonium leaked at the site, a value which is representative of the 903 area toxicity will eventually be determined. For the time being, an arbitrary value is used. Since this value is just a constant used as a multiplier for every calculation, it has no effect on the dose levels as they are shown relative to one another.

Activity inhaled and breathing rate

Obviously, a key factor in determining dose from inhaled toxic particles is the rate at which said particles are inhaled. The inhalation or breathing rate depends both on activity level and available lung volume, so breathing rate tends to increase as a person ages. Though men have a slightly larger lung capacity than women, the difference in breathing

rate is negligible, so all adults are treated the same in the spreadsheet, using a breathing rate that is actually the average of the accepted male and female values. The rates used appear in the spreadsheet, and are reprinted from the *RAC* report on plutonium risk factors currently in review (Grogan, Sinclair, and Voillequé, 1996).

The activity inhaled is determined by taking the air concentration multiplied by the radiotoxicity factor multiplied by the breathing rate. Activity inhaled is calculated for each distance, each age, and for gust and non-gust conditions. For an adult, two activity inhalation levels are calculated. The laborer value is a worst case calculation: for someone who inhales air at the high breathing rate 24 hours a day. The 12 hour laborer values only use the high rate from 6 am to 6 pm and the sedentary rate during the remaining hours.

At the bottom of each of the activity inhaled columns, a cell exists which sums the total activity over the month. This cell is then multiplied by the appropriate dose conversion factor, which also changes with age. The effective dose decreases as body size increases since the radiation dose to the body per unit intake would be affected by a body size increase, decreasing the dose per intake of particle. These values come from ICRP 56 (1989) and are again reprinted from the plutonium risk report (Grogan, Sinclair, and Voillequé, 1996).

The final value in each column takes the dose obtained and multiplies it by an arbitrary value of 10^{12} to convert the dose to numbers that are easier to understand and compare to one another.

Deposition velocity

Though inhalation is regarded as the major dose pathway for releases from the 903 area, it is important to show the difference in dose levels received from inhalation and from potential ingestion of plutonium contaminated soil.

Dust particles which have been resuspended into the air and transported downwind are subsequently available to be redeposited on the ground surface in remote locations. Since the air concentration has been shown to decrease dramatically when gusts are removed from the calculation, the deposition is only determined for concentrations which are found using the GAUS1 gust equations.

The first step in determining the amount of soil deposited is to find the deposition velocity. This is a very site-dependent parameter and is not easy to estimate unless an experiment is specifically conducted at the site of interest which results in the values needed to calculate the deposition velocity. Lacking this information, a paper published on deposition velocities calculated for different soil and particle size conditions was used to make an estimate (Sehmel and Hodgson, 1974). Studies done in the early 1970s on the land to the east of the 903 area calculated particle size (Sehmel, 1976). The average size ranged between 1 and 8 μm, with a relative median close to the 903 area around 3 μm. This value was used to determine the deposition velocity.

Assuming that most of the deposition probably occurred on relatively level ground in residential areas, it seems reasonable to assume that the deposition surface would be lawn up to 5 cm in height. For a surface such as this, in the Sehmel and Hodgson paper, values for friction velocity (u^*) and roughness height (z_o) are given as 0.43 m/s and 1-2 cm, respectively. Graphs are generated in the paper for varying deposition velocities for different values of all of the above quantities. From one of these graphs, an estimated deposition velocity of 1.5 cm/s was chosen. This value is given in the spreadsheet, as well as the conversion to m/s.

Toxic soil deposition

The mass of toxic soil deposited is calculated similarly to the mass inhaled. The air concentration is multiplied by the deposition velocity to give the soil deposited in units of grams per square meter per second. This is converted to Curies by multiplying by the radiotoxicity of soil defined earlier, leaving the activity deposited in units of Ci/m^2s. Each air concentration value was averaged over an hour, so the activity deposited is multiplied by 3600 s/hr. This value is then divided by the density of the soil and by the 1 cm of surface soil which is of interest for ingestion calculations, since that will theoretically be the top soil available for ingestion. This leaves a value referred to as the hourly total activity in the top 1 cm of soil in Curies of plutonium per gram of soil. If 25 grams of soil are ingested per day, 1.04 grams are ingested per hour, and this is multiplied by the previous value to give total Curies of plutonium ingested per hour. Total soil ingested can be readily changed in a single cell within the spreadsheet, and the cells which use this value in calculations will respond appropriately.

At the bottom of this column, the entire column is summed to give the total intake over the month. This is multiplied by the ingestion dose conversion factor. The same dose conversion is not used for ingestion and inhalation because it is recognized that plutonium inhaled into the lungs has a different biological effect than plutonium ingested into the gut as a result of the way the body metabolizes plutonium. The effective dose is again multiplied by the arbitrary conversion of 10^{12} to make comparison of the ingestion and inhalation doses possible.

LESSONS LEARNED FROM THE DOSIMETRY SPREADSHEET

The output of the 903 area dosimetry spreadsheet includes a variety of important results which aid in making decisions about pathways to consider, scenarios to develop, and further investigations to conduct. The graphs and charts which highlight the results in a visual format can be found in the attached copy of presentation handouts (appearing as Appendix B). It is important to remember that the doses calculated in the spreadsheet can be used to compare the effects of a number of different parameters and exposure pathways (e.g., inhalation vs. ingestion) on the final doses. The doses themselves are not the final dose results for this project. This spreadsheet allows for the possibility of witnessing the effects that various parameter changes have upon dose.

Effect of age on dose

Several different age classes, from infant to adult, were considered in the spreadsheet calculation. The factor which has the largest effect on age is breathing rate. As a person ages, the volumetric capacity of the lungs increases, consequently increasing the total volume of air inhaled over a given time period, and the effective dose of a radiation within the body changes as well. The effect that dose has on the body, or effective dose, decreases with age due to the larger body mass over which the dose is spread. When these two factors are combined, breathing rate and effective dose, the result is referred to as the hazard index, or the relative hazard to different age groups per unit intake of radioactive material. The

breathing rate, effective dose, and hazard indices, as well as the arbitrary dose values obtained from the spreadsheet calculation for each age group are shown below in Table 1.

Table 1: Age dependent Breathing Rates, Effective Doses, and Hazard Indices and estimates of effect on dose from the 903 Area[a]

Age	Breathing rate (m^3/hr)	Effective dose (rem/μCi)	Hazard index (rem m^3 / hr μCi)	Effective dose (rem x 10^{12})
Infant	0.07	890	0.07 x 890 = 62.3	0.909
1 year old	0.21	740	0.21 x 740 = 155.4	2.408
5 year old	0.36	520	0.36 x 520 = 187.2	2.887
10 year old	0.64	410	0.64 x 410 = 262.4	4.003
15 year old	0.74	360	0.74 x 360 = 266.4	4.066
Adult - Sedentary	0.86	310	0.86 x 310 = 266.6	no dose calc.
Adult - Laborer	1.12	310	1.12 x 310 = 347.2	5.302
Adult - 12 hr laborer	0.99	310	0.99 x 310 = 306.9	4.879

[a]Calculations were done for a receptor distance of 100 meters in a direction directly to the east of the 903 area

These doses are based upon a receptor distance of 100 meters from the edge of the 903 area. Dose was not calculated for a sedentary adult because it would be similar to that for a 15 year old. The results suggest that doses to adolescents and adults are roughly two (2) to five (5) times higher than those for younger children and infants when all other factors are the same. This makes it clear that adults and adolescents are the critical groups for doses resulting from exposure to plutonium from the 903 area.

Effect of gust conditions

The GAUS1 code, as mentioned earlier, has the advantage of inclusion of gust speeds within the source term calculation. For the spreadsheet we can include ("with gusts"), or exclude ("without gusts") these wind gusts in the calculations. The fraction of the time (min per hr) that gusts were observed is accounted for in the calculation. For the remaining time (min per hr) in the hour without gusts, the average wind speed is used as the value for that hour. In the spreadsheet, a value of four (4) minutes per hour was used for the gust frequency. Results show a two-fold increase with only a four minute per hour wind gust frequency.

Wind records recently discovered for the Rocky Flats area indicate that during a given time period, gusts are generally much more prevalent than four minutes per hour (~7%). Time fractions average more around 20% and peak around 60% in extremely gusty conditions.

Gusts and high wind conditions do, in fact, appear to dominate the dose. This is further confirmed within the 903 report (Meyer et al., 1996) by the correlation between high wind events and large releases recorded by the S8 counter at the 903 area perimeter. The high wind events occurring during the period of interest for the 903 area will result in the majority of the resuspension of the plutonium-contaminated material on the ground.

Effect of receptor distance from source

Two different receptor distances were used in the straight line Gaussian plume model to determine the dose. Concentrations and doses at a distance of 100 meters and a distance of 1000 meters were calculated for comparison. Increasing the distance by a factor of ten decreases the dose by more than ten-fold. For example, the doses to the adult laborer are 5.302 and 0.487 for the distances of 100 and 1000 meters, respectively. It is clear that as distance from the source increases, the dose drops off significantly.

Direction from the source and its effects

Most of the winds experienced along Colorado's Front Range tend to come primarily out of the west. This is confirmed by most modern day meteorological data as well as the data discovered for the time period of interest. The logical projection of that fact into this study is that the receptor locations of interest will be located to the east of the 903 area. This spreadsheet used the atmospheric dispersion code to determine the arbitrary dose values at a distance of 100 meters for receptors located to the north, south, east, and west of the 903 area using actual wind conditions measured during the period covered by the spreadsheet. All values quoted to this point have been determined for receptors to the east of the plant. The comparison to other directional values is shown in Table 2.

Table 2: Effect of direction from the 903 Area on Receptor Dose to an Adult Laborer[a]

Direction from the plant	Arbitrary dose (rem x 10^{12})
North	0.0679
South	0.0151
East	5.302
West	0.00522

[a]Doses are calculated for gust conditions at 100 meters from the 903 area

These doses are once again shown for gust conditions with receptor characteristics of an adult laborer. The level of dose received by the receptor to the east is dramatically higher than all other doses. Although actual wind conditions as measured during the month of January 1969 were used to complete these calculations, it is assumed that this basic trend represents other periods as well. This month was somewhat representative of wind conditions as seen over the entire time period to be modeled.

The dose to the north of the 903 area source was somewhat higher than the dose to the south, although winds directed to the southeast prevailed during most of the year. This is counterintuitive to the result presented here. It is important to remember that the calculation done in this spreadsheet is more like a snapshot taken each hour at the location of interest. The dose at each location is increased only when the source term for a given hour is moved in the direction of the receptor during that hour; that is, when wind direction during the hour modeled is in a direction such that the receptor will receive dose. Dose is not changed relative to potential movement of the radionuclide contamination as wind direction changes. Plume movement is not accounted for here as it will be in the final modeling

calculations done to determine dose. If a number of high wind events during this particular month occurred in northern directions, it seems reasonable that the higher "snapshot" type dose determined on an hourly basis might be to the north rather than the south. The real value of this calculation lies in the fact that the dose to the east is between two and three orders of magnitude higher than the dose in any other direction, with doses to the west remaining minimal. This observation contributes to other evidence that doses to the east of the 903 area are higher than those in other directions.

Inhalation pathways vs. ingestion pathways

Evidence suggests that inhalation dose will strongly dominate the total dose to an individual from releases from the RFP, and this spreadsheet tool was used to calculate to what degree that would be the case.

Doses were calculated for an active adult from both the ingestion and the inhalation of plutonium-contaminated materials from the RFP, and those doses were compared. A deposition velocity for grass, to 5 cm high, was used to maximize the dose. This yields a conservative estimate for deposition velocity with particles being scavenged out of the air and to the ground more rapidly than they would be to a bare surface. Another source of conservatism in this calculation is the estimate of total soil ingested. A value of 25 grams per day was averaged over 24 hours, resulting in approximately 1.0 g soil ingested per hour for an entire month. This is likely a huge overestimate of total soil ingestion and would yield a much higher value for dose than would normally be expected. The arbitrary dose value for ingestion at 100 meters with gust conditions for an adult is 2.06×10^{-6}, more than six orders of magnitude smaller than the inhaled dose estimate of 5.302. This strongly suggests that the ingestion of plutonium will contribute very little to the total dose from airborne plutonium-contaminated material. Because the inhalation of plutonium dominates the total dose, this provides strong evidence for not including diet as a parameter in the exposure scenarios. With dose dominated by the inhalation pathway, it is important to focus our resources on that pathway and to minimize our efforts for the ingestion pathway.

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APPENDIX A

The directional air dispersion calculation is somewhat complicated by the use of a straight line Gaussian plume model. This model uses a convention for the coordinate axes which dictates that the positive x-axis be in the direction that the wind is blowing. Since quite often the wind blows in directions other than those for which dose was to be determined, it was necessary to determine the appropriate x and y lengths for a distance 100 meters from the source directly to the east, west, north, or south.

In order to avoid determining the x and y lengths for every possible angle between 1 and 360 degrees, the direction vectors were separated into sixteen sectors, each spanning an angle of 22.5 degrees. Then the x and y lengths for wind directions which corresponded to the central axis of each of the sectors was determined. Any wind direction falling within that sector was assigned the x and y values for the central axis of that sector to determine the air concentration at the downwind location in the direction of interest.

In addition to separating the wind directions into sectors, other data for the time period of interest was used to separate the data and create a joint probability distribution. The stability classes were separated into the six Pasquill-Gifford classifications, and the average wind speed for each time period was separated into groupings as well. Then all of the data for the month being modeled was divided into a joint frequency distribution. The frequency with which the characteristics defining the conditions of each hour is seen within the month of interest is multiplied by the value obtained for air concentration to determine the average air concentration over the time period of interest, as shown by the following equations.

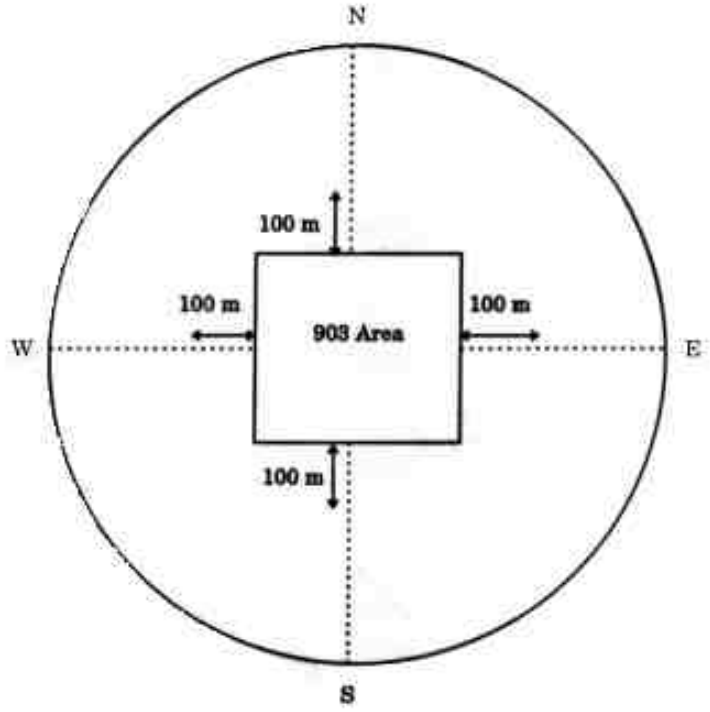
$f_{i,j,k}$ = number of hours the wind blew in sector i with windspeed class j and stability class k divided by the total number of hours of data available

$$C_{avg} = C(x,y) f_{i,j,k}$$

where C_{avg} = the average concentration for the period modeled

The result of these calculations is the air concentration and subsequently the dose in each of four directions from the 903 area: North (360), South (180), East (90), and West (270). Unfortunately, wind directions in standard meteorological data is given by the direction from which the wind originates, so if the wind is blowing directly to the east, the wind direction will be defined as the angle 270. This convention in meteorology requires "flipping" the classical understanding of coordinate axes in the opposite direction to determine the correct doses for the correct directions.

A figure which further explains the method used to determine dose in different directions from the 903 Area is shown on the following page.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Technical Memorandum

Examination of Mass Balance Accounting as a Means for Estimating Plutonium Releases

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May 1995

Introduction

Citizens interested in release estimates from the Rocky Flats facility have suggested that a mass balance approach should be used to estimate past releases. The idea is to compare the quantity of plutonium (Pu) brought onsite with the quantity of Pu leaving the site as a means of estimating past environmental releases of Pu from the facility.

The idea of using plutonium accountability data to assess the magnitudes of Rocky Flats releases was seriously considered at the start of Phase II. We had previously investigated accountability data at the Fernald facility in Ohio, which processed depleted, natural, and slightly enriched uranium (U). We found that there were large uncertainties in those data and that large quantities of uranium had been written off as unmeasured losses. However, it was thought that plutonium accountability data would prove to be more reliable because of the much higher value of the plutonium. Citizens have expressed this same idea: because plutonium was more valuable than gold, you would expect that those responsible would know where every last bit was.

The following sections describe the results of our investigation into Pu accounting at Rocky Flats, first for the major fires and then for routine operations. A summary of the results of the evaluation then follows.

Accountability Data for 1957 and 1969 Fires

One of our first goals while searching through the classified records at Rocky Flats was to identify information on plutonium accountability for the September 1957 fire in Room 180 of Building 71 and the May 1969 fire in Buildings 776 and 777. The search was successful. Records of the Pu loss for the 1957 fire were found in monthly accountability reports between the time the fire and completion of the final cleanup of Room 180 several years later. An accounting of the pre- and post-fire inventories of Pu in Buildings 776 and 777 was also found in the classified records.

We requested the declassification of notes taken while reviewing the 1957 fire data and of documents containing accountability data for both events. Information regarding the plutonium accounting for the two fires was declassified and released by Secretary O'Leary in June 1994, together with information on plant inventory differences at Rocky Flats and elsewhere.

For the 1957 fire, overall accountability from before the fire to the completion of cleanup showed a decrease in book inventory of 6 kg of plutonium. Following the 1969 fire, more (104 kg) Pu was recovered that had been in the inventory prior to the fire. These results illustrate that there are difficulties associated with the use of accountability data to estimate releases. Just as the latter finding does not mean that there were no releases to the environment during the 1969 fire, the reported inventory difference for the 1957 fire does not imply that the 6 kg of Pu was released to the environment.

Example of Accountability Data for Routine Operations

To further evaluate the utility of the mass balance approach, routine operation of a Pu processing facility was considered. The following example estimates plutonium mass balance data for such a facility.

The quantities received and shipped, the numbers of shipments, and the building inventory used in the discussion are not data from Rocky Flats but are speculative estimates of possible levels of activity for this discussion. Declassified information released by Secretary O'Leary (June 1994) show that the Savannah River Site produced about 1500 kg of Pu per year during the early 1960s. If Rocky Flats received that Pu and a comparable amount from a combination of weapon returns and Hanford production, then the annual receipts would be 3000 kg. This corresponds to an average of 250 kg per month, the rate used in this example.

Other quantities needed for the analysis are explicitly based upon published information for Rocky Flats. The estimated releases from the facility used in this example reflect the highest Building 71 releases that were measured during the 1960s. The release estimates and the uncertainties associated with those measurements are still being reviewed as part of Phase II, but are considered adequate for this example.

For the example, the amounts of Pu in waste shipped to the Burial Ground at the National Reactor Testing Station (names used at the time) in Idaho and the numbers of barrels of waste generated per month are representative of estimates reported at that time. The estimated size of the inventory difference (ID) is also consistent with data from Rocky Flats operations. Annual inventory differences of 100 kg were common during the early 1960s and comparable quantities were used in the example.

Details concerning assumptions and estimated quantities and the corresponding uncertainties in the main elements of the mass balance for the facility for an average month of operation are listed below.

Input: monthly receipts of 250 kg Pu in 10 shipments of metal or other form having an average Pu mass of 2500 g; the amount of Pu in each of these shipments could be weighed to within 0.1 gram.

Outputs: monthly shipments of 220 kg Pu in 11 packages having an average mass of 2000 g Pu; the mass of Pu in each of these shipments could be weighed to within 0.1 gram.

Measured losses consist of routine releases to the atmosphere and to Walnut Creek and shipments of solid wastes to Idaho.

(a) measured release from the stack: a total of 600 μCi of $^{239/240}$Pu in a month. An estimated uncertainty range of 300–1200 μCi is assumed because of use of a single sampling point in the large exhaust duct. (Effluent monitoring data and the uncertainties associated with those measurements are still being reviewed as part of Phase II).

(b) measured releases in liquid discharges to Walnut Creek: a monthly total of 500 μCi of $^{239/240}$Pu. An estimated uncertainty range of 250–1000 μCi was chosen to reflect use of gross alpha counting and no information on the mixture of U and Pu in the liquids discharged in the liquid waste stream, which also contained liquid from U processing in other buildings. (Effluent monitoring data and the uncertainties associated with those measurements are still being reviewed as part of Phase II).

(c) estimate of amount of Pu in solid wastes shipped to Idaho: a monthly total of 2.5 kg in 300 barrels. The amount is more likely to be underestimated than overestimated because of difficulties in sampling discarded components and mixtures of solid materials. A preliminary uncertainty range of 1–9 kg is employed in the example. Current estimates of the Pu in buried waste in Idaho are about three times greater than original estimates.

Building Inventory: at the end of the month an inventory of the facility identifies 18 kg of Pu in components being fabricated and in identifiable scrap material. Although particular pieces can be weighed with the same precision identified above (±0.1 g), incomplete identification of scrap fines in process equipment leads to an estimated uncertainty in the inventory quantity of 0.1%.

The following table summarizes the estimated quantities with uncertainty estimates based upon the assumptions given above. The uncertainties in the receipts (R) and shipments (S) reflect the total uncertainty for the month; that is, the combined uncertainties for the individual shipments. The example releases to air (A) and water (W) have been converted to mass, as shown. Preliminary estimates of uncertainties in these quantities were discussed above; they will be refined later following further investigation. Estimates of uncertainties in the amount of Pu in shipments of solid wastes (SW) and in the monthly building inventory (BI) also correspond to the foregoing discussion.

Each of these elements of the mass balance is used in the calculation of inventory difference (ID) for the period. The equation used is

$$ID = R - S - (A + W + SW) - BI$$

The uncertainty range for the inventory difference reflects the uncertainty ranges for all the quantities used in the calculation.

Example Mass Balance for Plutonium Processing Facility

Mass balance element	Measured mass (kg)	Uncertainty in mass (kg)
Pu received by facility (R)	250	$\pm 3.2 \times 10^{-4}$
Pu sent from facility (S)	220	$\pm 3.3 \times 10^{-4}$
Pu in releases to air (A)[a]	8.3×10^{-6}	$0.42–1.7 \times 10^{-5}$
Pu in releases to water (W)[a]	6.9×10^{-6}	$0.35–1.0 \times 10^{-5}$
Pu in solid wastes (SW)	2.5	1–9
Building Pu inventory (BI)	18	± 0.018
	Estimated (kg)	
Inventory difference (ID)[b]	9.5	3–11

[a] Estimates (μCi) were converted using a specific activity of 0.072 μCi/μg.

[b] Computed using the equation: ID = R – S – (A + W + SW) – BI.

Some features of the tabulated estimates in the table deserve particular attention. First, the elements in the mass balance evaluation are not of commensurate magnitudes. The monthly receipts, shipments, and building inventory elements are much larger than the solid waste component and the latter is very much larger than the highest measured monthly releases of plutonium to air and water. The largest uncertainties in Pu mass are in those for the solid waste disposal and building inventory categories.

The first feature is notable because of a previous review of the utility of the material balance approach. In an independent review for the Environmental Protection Agency, as part of the Superfund Amendments and Reauthorization Act of 1986, the National Academy of Sciences (NAS) concluded that when there are major disparities in quantities processed and released, the engineering mass balance approach has no potential value in determining releases by difference (Tracking Toxic Substances at Industrial Facilities, National Academy Press, 1990). The results in the table illustrate numerically the NAS conclusion for the semi-hypothetical Rocky Flats facility.

Because the quantities received and shipped could be determined with great precision, the uncertainties in R and S are small, about one part in one million in the example. Even so, these uncertainties alone are 20–80 times larger than estimated amounts of Pu released to air and water. The range of the ratio was computed using the alternative release estimates listed in the column showing the uncertainty ranges of A and W. The comparison reflects uncertainty bounds on the highest monthly release estimates previously recorded. As noted, the measured effluent releases and their uncertainties are subjects that we are still reviewing and the computed ratios may be revised. Overall uncertainties in the input and output quantities depend on the numbers of incoming and outgoing shipments. Assuming different numbers of packages would affect the uncertainties in R and S somewhat, but they would remain substantially greater than the tabulated ranges of releases to air and water based on plant measurement data.

The estimated uncertainty in the month-end building inventory of Pu is less than 0.01% of the Pu processing rate assumed for this example. However, that uncertainty of ~0.02 kg also greatly exceeds the highest recorded monthly discharges in gaseous and liquid wastes.

Uncertainties in the amount of Pu in solid waste shipped offsite for burial are even larger and dominate the overall uncertainty of the inventory difference. These uncertainty estimates reflect the fact that for many years there was no reliable way to measure the amount of plutonium in waste shipments. Gamma ray surveys of the barrel exterior could detect the presence of elevated amounts of the contaminant ^{241}Am, but interpretation of the measurement depended upon knowledge of the waste matrix. Smears surveys could measure levels of contamination on discarded equipment and other wastes, but were unable to detect material trapped in crevices. Even with contemporary equipment, measurements of Pu in solid wastes are difficult and uncertain.

Summary

Although it was initially expected that a mass balance approach would be useful in the evaluation of releases from a plutonium facility, this review shows that it is not feasible to make quantitative estimates in this way. For routine operations, this conclusion is in agreement with a previous NAS report that assessed the same question for chemical processing facilities.

For early plutonium operations at Rocky Flats, (a) large uncertainties in solid waste measurements and (b) uncertainties in inventory estimates due to material held up in processing lines are both estimated to be much greater than measured effluent releases. Although the difference is smaller, uncertainties associated with measured receipts and shipments also appear to be substantially greater than the highest reported plant releases. Review of the effluent release data is continuing and the relative magnitudes of the quantities assumed in this evaluation may change.

From HAP transcripts May 25, 1995 (afternoon)
Discussion of mass balance during P. Voillequé's 1957 fire presentation.

Well, let's see.

Okay. I guess this is a slide that some of you have seen before that has to do with--with using a mass balance approach. Before the fire, we have plutonium in the room and--and masses of plutonium that were on the--had been collected on the filters.

After the fire, plutonium was recovered. There was solid and liquid waste from the cleanup. There was residual plutonium contamination on the walls of the room. Particular--this is particularly true of Room 180 which was ultimately decontaminated with paint. And that is to say, the contamination was covered up by multiple layers of paint. And then there was airborne effluents.

There was a time when I thought, and a time actually when I showed these slides, that it would be possible to do some sort of material balance calculation using information from the plant. This is just another way of saying the same thing. Initially, we had this amount; finally, we had these quantities. You can solve that equation to get the amount released to the atmosphere. That's the initial amount minus these--the recovery and the residual contamination with the waste.

But what you find out when you dig deeper into this, is that you can't do this calculation because this amount of waste is not known and that the solid

wastes that were shipped from the plant--the plutonium and solid waste shipped to the plant in Idaho was not measured. And so this approach falls apart.

I have--because it's of interest in this regard, I have put together some of the information on material I accounted for as a function of time. This is again from the Zodtner and Rogers investigation of the material unaccounted for that occurred in 1964.

And at the end of fiscal 1963, there was a lot of material unaccounted for. And you can imagine that that might be enough to cause an investigation. 664 kilograms is a lot of plutonium.

1953, relatively little material unaccounted for; '54, growing; growing, '56. These are cumulative--excuse me. These aren't annual amounts. These are cumulative. At the end of '53, at the end of '54.

At the end of September--these data are given quarterly, so I was able to get a number for the end of September which was about 69 kilograms. But then you can see at the end of all of '57, is about 82. And then we skip to 1960 and to the end of fiscal '63.

After 1957--there were roughly 35 kilograms of material unaccounted for in '57 which do not include material involved in the fire because

this accounting wasn't completed until the end of 1961. But in the years '58--starting with '58 through '60 and on to '63, typically, a hundred--in round numbers, a hundred kilograms of plutonium a year was in the category of material unaccounted for.

Now, so that--the fire investigation.

DR. SCHONBECK: Paul.

MR. VOILLEQUE: Yes. Sorry.

DR. SCHONBECK: Are these numbers site life or are they building specific?

MR. VOILLEQUE: This is--this is plutonium material unaccounted for. And so until this time, it refers primarily to Building 71 because 76 and 77 just were just beginning to operate in '57. But many of the--then many of the losses--well, then following this time when we started to see a hundred kilograms a year, it's a combination of 71 and also of 76 and 77.

MR. ALBRIGHT: And prior to this 1957, it would be in Building 71. And how much of that would be in--in Room 180? 180, is that representation a small fraction of the entire operation?

MR. VOILLEQUE: Yeah.

DR. SCHONBECK: Okay. So this represents the site wide.

MR. VOILLEQUE: This is all of--this is

all of Building 71 essentially up to this point. And you have to remember that this development work, that picture I showed you when--when those glovebox lines in Room 180 were shiny and new was taken in the spring of 1957. So this is a relatively new piece of an ongoing operation.

DR. SCHONBECK: And then to follow that up, did you run across any kind of commentary in the documents to indicate concern about this kind of loss?

MR. VOILLEQUE: Well, as I said somewhat facetiously, it's not surprising that an investigation was initiated when it got to be 600 kilograms.

And--but I don't know whether what--I mean, I can't explain--well, a couple of things.

One, I haven't seen significant--well, or any indication of previous investigations of material unaccounted for. It--it was routinely reported in those--those lovely reports that I showed you some numbers from earlier, those October and November reports.

Also in those reports were--material balancing information is given, and it would oscillate back and forth. One month, you may have lost some material; the next month, you know, some material appeared, and so on.

But it was--I don't recall seeing earlier than this any detailed investigation. I mean, in the

monthly reports, there would be statements about, well, we believe this is due to X, Y, and Z. And maybe the next month, it would be that they found out that X, Y, and Z was, in fact, the case and they referred to that and said, well, we think it's something else.

But--but sort of a comprehensive investigation put together in one place, I don't think they had that.

Yeah. Dave.

MR. ALBRIGHT: I think it's important to add that the throughputs of the plant were increasing dramatically during this period from--the throughputs are still classified but--from headquarters.

CHAIRMAN QUILLIN: David, can you use your microphone, please.

MR. ALBRIGHT: All right.

It's--it's important to remember on these numbers that the throughputs in the plant were going up dramatically. And so the--the headquarters has said that they'll probably--they'll probably release the throughputs in the building, but they have to go through the formal process. But from--from '53 to '63, it's--it's a huge increase in throughput.

And--and so you--and also, I think just--this is more speculation. By '63, the--we were

making so many nuclear weapons that I imagine they were looking for plutonium everywhere. And--and--and they probably started seeing that there were huge amounts ending up in--in recoverable--potentially recoverable materials.

MR. VOILLEQUE: Yeah. That brings up another point.

Prior to this time, there was no--a lot of you probably heard about the economic discard limit. And that's--that's--that refers to an evaluation of how much it would cost to process and recover the plutonium in--in some material versus the value of plutonium at the time. That discard limit did not exist in the early years.

So there--the sort of routine analysis of--of should we reprocess this material or is it okay to throw it away wasn't going on.

And--and I guess the--in terms of--in terms of the--the waste or the potentially waste material reprocessing capabilities, I--as I recall, there's in 19--in the early years, say maybe up to '57, there--the throughput for the recovery process was potentially something like 25 kilograms a month. But by 1962, it was 600 kilograms a month. And that's another indication of the kind of scale-up that--that Dave was talking about.

And later on, when we talk about the

ventilation system some, you'll see. In fact, you may have already seen the growth in the flow rate through the ventilation system. And this grew because initially it was only a day-shift operation. Subsequently, some of the operations went to two shifts. Ultimately, a lot of it--a lot of operations were--were 24 hours a day. And that reflects this scale-up in--in production capacity that David was referring to.

The investigation of material unaccounted for that took place in 1964 identified that there were a number of ways that plutonium had not been accounted for that contributed to this--this material.

One thing that you need to understand is that material unaccounted for doesn't necessarily mean that it--it was all waste or that it was all--that it was all discharged through the environment or anything like that.

One of the most surprising things to me reading this report, a deleted version of which is available, is that radioactive decay was a nontrivial contributor to the material unaccounted for. They hadn't taken account of radioactive decay. And when you're dealing with large quantities of plutonium, that can be--that can be an important factor.

It wasn't as important, however, as not

accounting for plutonium sent off in solid waste. This analysis that they did, some of which is--is based on detailed measurements of concentrations in waste such as casting residues in bowls where the graphite was shipped off site as waste, they--they made a bunch of measurements of those--of concentrations of that material to come up with their estimate.

But overall, they attributed about two-thirds of the--of that 660 kilograms to materials that had been disposed of in waste. And the biggest categories were the--the graphite molds and the--and filters from various parts of the building that had been sent off site without taking credit on the books for how much plutonium was contained in those materials. And so this material disappeared from the inventory because it's in wastes that were shipped away that were--wherever the quantity of plutonium was never quantified, was never measured, and it was not accounted for.

I mentioned radioactive decay. Oxide losses on returns. Some of the plutonium on--on returned bomb parts had oxidized. And this oxide was wiped off when this material came back. And overall, as I recall the numbers, they estimated that some 40 kilograms in that--that wiped-off material was--was lost from the system. And they estimated that that accounted for about

40 kilograms.

They also identified holdup in the buildings which became really obvious after the 1969 fire as being a significant contributor to material unaccounted for.

MR. FOUNTOS: Excuse me, Paul.

MR. VOILLEQUE: Yes.

MR. FOUNTOS: Could you clarify what is meant by holdup in the buildings. Is it just material that fell on the floor or something?

MR. VOILLEQUE: Well, not on the floor; in the gloveboxes.

Well, you've got--you've got to envision inside these gloveboxes, hydraulic presses and lathes that are used to shape metal pieces and stuff like that. So there are turnings and things that fall down in the cracks. And even when they cleaned the gloveboxes out for the inventories, they didn't find all those bits and pieces. So that's one source of holdup in the buildings.

Another source of holdup in the buildings that's--that's been of particular concern for Building 707 is--is deposition of material in the exhaust ductwork. There are some ducts that are comparable to those booster exhaust pipes that I showed you in the previous slide that have been found to be filled with mixtures of--of

plutonium-contaminated material that's gotten off as a result of processing in the glovebox that they served. And so there's a lot of material in the pipes. And in recent years, they have actually done standing measurements to determine the amount of material that's--that's in the pipes. That's another example of holdup.

MR. FOUNTOS: Thank you.

MR. VOILLEQUE: Yes. Bill.

DR. KEMPER: I suppose all the material that's in the pipelines--

MR. VOILLEQUE: Well, I think it's--

DR. KEMPER: By that, I mean in process at the time that they were taking the measurements.

MR. VOILLEQUE: The material that's flowing inside the system in the glovebox, that's accounted for except for the little bits and pieces that are caught in the cracks and so on. That's the kind of holdup they're talking about, the not readily identifiable or measurable in pieces or the bits and pieces that are in the cracks.

Yes.

DR. SCHONBECK: Did they give any estimates from the radioactive decay losses? I mean, I've made calculations for 239, and it's minuscule.

MR. VOILLEQUE: Well, that's true, but--

DR. SCHONBECK: So 241, I mean, it's a small percent.

MR. VOILLEQUE: It's piqued my interest. As I said, I'm very surprised to see this.

And it has to be--I've done some calculations, and it has to be due to the 241 even though the 241 is less than half a percent of the total amount. It's if you got a large mass of plutonium, half a percent of a large mass is itself pretty large. And it's decaying with the 14-year half life.

DR. SCHONBECK: But let me follow that up.

If it doesn't decay to nothing, the mass loss is so small. Are we talking about that after purification as a--

MR. VOILLEQUE: It decays to americium which--

DR. SCHONBECK: Yeah.

MR. VOILLEQUE: --which disappears.

DR. SCHONBECK: It doesn't disappear.

MR. VOILLEQUE: Well, no, it doesn't disappear. It disappears from the plutonium accounting system.

The mass doesn't change, but they don't keep track of Americium 241.

DR. SCHONBECK: You're presuming now that that accounting comes in after they've purified the americium away from the plutonium.

MR. VOILLEQUE: Right.

DR. SCHONBECK: Because otherwise, you would just put it on a balance.

MR. VOILLEQUE: No. No. Those losses--those decay losses are not--are not based on--on measurements, okay?

We make a bomb. We send it--well, we make several hundred bombs. We send them off to the stockpile, okay? And they come back--the average time they estimated was three years. They come back three years later and they've got less plutonium in them than they had when we sent them off.

DR. SCHONBECK: Now, how do they establish that they had less?

MR. VOILLEQUE: Well, it's--the laws of nature establish that they have less.

DR. SCHONBECK: Well, I know. But what is the measurement?

MR. VOILLEQUE: There is no measurement.

DR. SCHONBECK: Oh, it's just presumed.

MR. VOILLEQUE: Well, it's not a presumption. We know that Plutonium 241 decays.

DR. SCHONBECK: Well, here is my confusion. We're talking about measured losses, right? In terms of unaccounted for--

MR. VOILLEQUE: We're talking about contributions to material unaccounted for--

DR. SCHONBECK: Now, but how that--

MR. VOILLEQUE: --that has not previously been taken into account. One of these is radioactive decay.

You send this material away and it stays away for a certain period of time. It comes back. We receive it as the same amount as we sent.

MS. GROGAN: But it's not the same amount.

MR. VOILLEQUE: But it's not the same amount. And that amount is the contribution from radioactive decay that occurred while it was gone.

DR. SCHONBECK: I understand the calculation. But at some point, there is a measurement years later. And is this what--is this what they're trying to account for? And it comes after the purification?

MR. VOILLEQUE: Yeah. Well, the measurements--the unaccounted-for totals are totals of plutonium.

DR. SCHONBECK: Right.

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May 19, 1995

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Dear Dr. Morin:

As we discussed on the phone last week, the presentation relating to the **collection efficiency of ambient air samplers** will be incorporated into the September Health Advisory Panel meeting, rather than the upcoming meeting this month. However, with this memo, I would like to summarize the approach we are taking to evaluating the collection efficiency of the ambient air samplers historically used around Rocky Flats. If any member of the public or the panel would like to contact me with suggestions or additional information, I would be happy to speak with them.

The historical air monitoring record is one of the most important of the environmental monitoring data sets available to us on this project, because it most closely reflects the pathway of primary exposure of the public to past releases, that is, airborne transport of released materials. However, the air monitoring record has limitations, especially when used for source term verification/model validation. These limitations can be grouped into those related to lack of data and those related to interpretation of the data we do have.

Examples of Limitations of Historical Air Monitoring Record for Source Term Verification/Model Validation

Limitations Relating to Lack of Data	Limitations Relating to Quality or Interpretation of Existing Data
No Pu-specific analyses routinely performed before 1970	Must establish relationship between gross alpha and plutonium concentrations
Pu isotopic ratios (239:240) not routinely measured	Difficult to distinguish RF Pu from fallout Pu (not likely possible more than a few km away)
Short-term releases may have missed the samplers; no routine collection of different particle sizes until recently	Must determine collection efficiency of air samplers for the different particle sizes believed to be present
No routine monitoring at various heights above ground	Must use weather records and models to calculate total amount released; requires assumption of vertical profile of contamination
No monitoring for organic solvents	

Even with the obvious limitations, the air monitoring record must be evaluated carefully for the dose reconstruction work to be complete. We have devoted much effort to establishing a basis for interpreting the environmental data which are available. The collection efficiency of the air samplers is an example of one of these data interpretation issues. Quite justifiably, this issue has been raised a number of times by members of the public who are involved with this project.

Simply speaking, the collection efficiency of an air sampler is a measure of how accurately the sampler captures the true airborne concentration of the contaminant of interest. For example, if the true airborne concentration is 100 units, and the air monitoring procedure produces an estimate of 80 units, then the collection efficiency would be 80%. (Analytical bias is not considered here).

The collection efficiency of an air sampler can be viewed as having two components:

1. The inlet collection efficiency of the sampling device (how accurately the device draws the ambient aerosol into the filter);
2. The filter collection efficiency (the amount of the material drawn into the filter that is retained by the filter, i.e., does not pass through it).

Properties of the air sampler which affect collection efficiency include:

- Inlet face velocity of the incoming air (related to flow rate)
- Placement height and orientation
- Type of shelter or housing
- Filter characteristics

Properties of the environment, such as wind speed and orientation with respect to the sampler inlet, also affect collection efficiency. The particle size (aerodynamic diameter) of the contaminant aerosol being collected is another key property of the environment affecting collection efficiency. It is useful—in conducting a general discussion of this issue—to think in terms of *coarse* and *fine* aerosols. Small particles making up fine aerosols tend to behave like molecules and follow the air stream into the sampler; the large particles in coarse aerosols have sufficient inertia that they tend to move in straight lines, not following curved air trajectories. For coarse aerosols, aerodynamic effects in the air outside the sampler are strongly dependent on wind speed, turbulence, orientation effects, etc.; for fine aerosols, such effects are much reduced.

Collection of coarse aerosols is sometimes accomplished by various deposition collectors such as sticky paper and dust deposit gauges. A limited amount of this type of sampling was conducted at Rocky Flats; we are also examining these data. Air samplers are used to collect the finer aerosols. They are generally inefficient collectors of coarse aerosols, due to poor inlet collection efficiency and reproducibility (Vincent 1989).

It is widely observed that true isokinetic sampling of air under field conditions is impossible due to changing wind velocities and directions. Garland and Nicholson (1991) summarize some important common features of studies of air sampler performance:

> "...all the published tests show some common features: the sampling efficiency declines with particle size and also with ambient wind speed. .... Orientation may be important for non-symmetrical inlets. The dependence of efficiency with so many parameters makes it improbable that any correction can be successfully applied to filter samplers operating in field conditions. Few of the filter samplers investigated have had a satisfactory sampling efficiency for particles larger than 30 μm, and it is unlikely that any can sample particles larger than 100 μm."

Several wind-tunnel and field-intercomparison experiments on the Rocky Flats-designed Surveillance Air Sampler used in the 1970s have evaluated the spectrum of particle sizes collected. Site-specific documentation on samplers used prior to that time has not been located. Therefore, for interpretation of earlier air monitoring data, we must rely on studies of similar samplers and an assessment of basic physical principles. A larger degree of uncertainty will be applied to data from those earlier time periods.

Information is also being collected on the samplers used by the Health and Safety Laboratory and the Public Health Service, as these monitoring networks provide an important historical trend for fallout plutonium. These data were discussed at the February 1995 HAP meeting.

Of the Rocky Flats samplers, the onsite samplers and those downwind of the 903 area were probably faced with the largest proportion of coarse aerosols of Pu. Studies have been conducted (mainly in the 1970s and later) of the concentration and particle sizes of suspended Pu at different distances and heights above the ground (see attached list). Because of the changing nature of the releases from the 903 area, as well as the routine releases from the stacks, the particle size distributions of released Pu (and hence the air sampler collection efficiencies) are time-dependent.

We were faced with a similar problem in interpretation of historical air sampling data for the Fernald Dosimetry Reconstruction Project. That facility emitted a wide spectrum of particle sizes, some quite large, which varied over time. For most of Fernald's operating history, the ambient air samplers were quite close (within 0.5 km) to the release points, so that coarse particles were still present in the air. Our approach was to produce a description of the uranium particle size distribution at the location of each air sampler, based on the reconstructed source term and the deposition properties of various particle sizes. Then we developed a collection efficiency, with associated uncertainty, for each air sampler and year, based on the physics of aerosol collection for the type of sampler used. We will attempt to do a similar analysis for the Rocky Flats air monitoring record. I am working closely with Paul Voillequé and Bob Meyer of our research team on the particle size characteristics of the sources. George Killough and Art Rood will be involved in the particle deposition assessment.

The collection efficiency is an important consideration in dose reconstruction when the air monitoring data are used for verification of the source term/model validation. However, it should be emphasized that the particle size range which is important for internal dose assessment should have been efficiently collected by the samplers. In fact, the total mass concentration of radioactive particles is a rather poor indication of the inhalation hazard of an aerosol. There is now the widespread view that, if just one aerosol fraction is to be

collected relevant to health for a wide range of types of aerosol in the ambient atmosphere, then that fraction should be relevant to the deposition of particles in the lung (Vincent 1989). Inhalability and deposition of particles in the lungs is a function of particle size, and modern-day samplers are often designed to cut off the largest particle sizes and collect only the respirable fractions, sometimes subdivided into certain size categories. Depending on the particle sizes of the source term, the total mass concentration and the respirable mass concentration may be quite different.

In more recent years, there has been routine monitoring of specific particle sizes by the RFP contractor (EG&G) and the Colorado Department of Public Health and Environment, in addition to the special studies addressing these issues (see Attachment). Results from these relatively recent studies may be applicable to some earlier time periods, if the release mechanisms are similar. However, concentrations in recent years have been barely detectable in many cases.

There are a number of literature sources, some specific to Rocky Flats and some not, which can be used to assess the collection efficiency and uncertainty of the samplers, when faced with a certain ambient aerosol. There are over 60 documents currently in our ROCKY document database (used for Task 4, "Evaluation of Historical Environmental Data") which relate to particle size and/or collection efficiency of air sampling equipment. In addition, there are 34 documents in the ChemRisk document set from Phase I which relate to particle size in air or soil. A list of both these sets of documents is attached to this memo. It would be very helpful if the Panel or public would let me know of any other relevant sources of information. We are confident that this issue will be thoroughly researched and documented, and that the uncertainties in collection efficiency will be appropriately accounted for in interpretation of the historical air monitoring record.

Again, I look forward to receiving any feedback on our approach to the collection efficiency issue. I plan to attend the September HAP meeting, and would be happy to discuss this in more detail then, if there is time on the agenda.

Sincerely,

Susan K Rope

Susan K. Rope
Consultant to ***Radiological Assessments Corporation***
Phase II, Rocky Flats Dose Reconstruction Study

encl.: document list
copy to: RAC team via CAPS

Attachment to S.K. Rope Collection Efficiency Memo of 5/19/95

The following attachment is a printout of documents from the "ROCKY" Task 4 database and the ChemRisk document database satisfying the following search criteria:

"PARTICLE SIZE" OR "PARTICLE-SIZE" OR "EFFICIENC"

For the ROCKY database search, the search was applied to either the title or the description fields.

The ChemRisk document collection, from Phase I, has been transferred to Phase II researchers. All documents listed are in our possession and have been reviewed.

Please contact Sue Rope [phone (208) 522-5367; FAX (208) 523-5792)] to provide additional information sources.

Author LEARY J.A. **Date** 06/01/51 **Copy_to** SR
Title PARTICLE-SIZE DETERMINATION IN RADIOACTIVE AEROSOLS BY RADIOAUTOGRAPH

Author ALERCIO J.S. AND J.H. **Date** 01/01/52 **Copy_to** SR
Title EVALUATION OF ALPHA-PARTICLE ABSORPTION BY FILTER PAPER

Author SMITH W.J. AND N.F. **Date** 01/01/53 **Copy_to** SR
Title PROPERTIES OF VARIOUS FILTERING MEDIA FOR ATMOSPHERIC DUST SAMPLING

Author LIPPMANN M. AND W.B. **Date** 01/01/62 **Copy_to** SR
Title SIZE-SELECTIVE SAMPLERS FOR ESTIMATING "RESPIRABLE" DUST CONCENTRATIONS

Author ROBSON C.D. AND KIRK E. **Date** 10/01/62 **Copy_to** SR
Title EVALUATION OF AIR PARTICULATE SAMPLING EQUIPMENT

Author LOCKHART, L.B. JR.; **Date** 12/01/62 **Copy_to** SR
Title INTERCALIBRATION OF SOME AIR MONITORING SYSTEMS

Author LINDEKEN C.L.; R.L. **Date** 01/01/63 **Copy_to** SR
Title COLLECTION EFFICIENCY OF WHATMAN 41 FILTER PAPER FOR SUBMICRON AEROSOLS

Author LOCKHART L.B. JR., R.L. **Date** 03/20/64 **Copy_to** SR
Title CHARACTERISTICS OF AIR FILTER MEDIA USED FOR MONITORING AIRBORNE RADIOACTIVITY

Author KIRCHNER, R.N. **Date** 08/01/66 **Copy_to** SR PV
Title A PLUTONIUM PARTICLE SIZE STUDY IN PRODUCTION AREAS AT ROCKY FLATS

Author ANONYMOUS **Date** 01/01/70 **Copy_to** SR PARTS TO: KM MC
Title QUESTIONS CONCERNING THE MAY 11, 1969 FIRE AND NORMAL OPERATIONS

Author ANONYMOUS **Date** 01/01/70 **Copy_to** SR PARTS TO: KM MC
Title QUESTIONS CONCERNING THE MAY 11, 1969 FIRE AND NORMAL OPERATIONS

Author HIDY G.M. ET AL. **Date** 06/01/70 **Copy_to** SR
Title OBSERVATIONS OF AEROSOLS OVER NORTHEASTERN COLORADO

Author NATHANS, M.W.; HOLLAND, **Date** 10/13/71 **Copy_to** SR HRM
Title THE SIZE DISTRIBUTION AND PLUTONIUM CONCENTRATION OF PARTICLES FROM THE ROCKY FLATS AREA.

Author VOLCHOK, H.L.; R. KNUTH; **Date** 01/01/72 **Copy_to** MC SR CR FILES
Title PLUTONIUM IN THE NEIGHBORHOOD OF ROCKY FLATS, COLORADO: AIRBORNE RESPIRABLE PARTICLES

Author VOLCHOK, H.L.; KNUTH, **Date** 01/01/72 **Copy_to** SR
Title PLUTONIUM IN THE NEIGHBORHOOD OF ROCKY FLATS, COLORADO: AIRBORNE RESPIRABLE PARTICLES

Author HAYDEN J.A. **Date** 09/04/73 **Copy_to** SR
Title TRACKING PLUTONIUM AT ROCKY-FLATS

Author KREY, P.W.;KNUTH, **Date** 09/01/74 **Copy_to** SR TW MC HRM DS
Title INTERRELATIONS OF SURFACE AIR CONCENTRATIONS AND SOIL CHARACTERISTICS AT ROCKY FLATS

Author HAYDEN J.A. **Date** 09/05/74 **Copy_to** SR MC HRM
Title CHARACTERIZATION OF ENVIRONMENTAL PLUTONIUM BY NUCLEAR TRACK TECHNIQUES. SPEECH

Rocky Database - Author/Title/Date/Copy to

Author	SEHMEL G.A.	Date 02/01/75	Copy_to CRISK FILES; SR
Title	A POSSIBLE EXPLANATION OF APPARENT ANOMALOUS AIRBORNE CONCENTRATION PROFILES		
Author	MAY K.R., M.P. POMEROY	Date 01/01/76	Copy_to SR
Title	SAMPLING TECHNIQUES FOR LARGE WINDBORNE PARTICLES		
Author	BARKER C.J.	Date 01/12/76	Copy_to SR
Title	SPECIAL STUDY OF PLUTONIUM IN AMBIENT AIR		
Author	BARRICK C.W.	Date 01/21/76	Copy_to HRM
Title	PUO2 PARTICLE SIZE DISTRIBUTION IN SOILS		
Author	BARKER C.J.	Date 03/08/76	Copy_to SR
Title	SPECIAL STUDY OF PLUTONIUM IN AMBIENT AIR		
Author	BARKER C.J.	Date 04/01/76	Copy_to SR
Title	SPECIAL STUDY OF PLUTONIUM IN AMBIENT AIR		
Author	JOHNSON C.J.; R.R.	Date 08/01/76	Copy_to SR
Title	PLUTONIUM HAZARD IN RESPIRABLE DUST ON THE SURFACE OF THE SOIL		
Author	SEHMEL G.A.	Date 09/01/76	Copy_to SR AR HRM DS
Title	AIRBORNE 238PU AND 239 PU ASSOCIATED WITH LARGER THAN "RESPIRABLE" RESUSPENDED PARTICLES AT FOCKY FLATS DURING JULY 1973		
Author	J. A. HAYDEN	Date 11/02/76	Copy_to
Title	PARTICLE SIZE ANALYSIS--FILTERS FROM 707 BUILDING		
Author	PATTENDEN N.J. AND R.D.	Date 01/01/77	Copy_to SR
Title	THE PARTICLE SIZE DEPENDENCE OF THE COLLECTION EFFICIENCY OF AN ENVIRONMENTAL AEROSOL SAMPLER		
Author	MCDOWELL W.J.; F.G.	Date 01/01/77	Copy_to SR PV
Title	PENETRATION OF HEPA-FILTERS BY ALPHA RECOIL AEROSOLS		
Author	WEDDING J.B., A.R.	Date 01/01/77	Copy_to SR
Title	LARGE PARTICLE COLLECTION CHARACTERISTICS OF AMBIENT AEROSOL SAMPLERS		
Author	HAYDEN J.A.	Date 09/22/77	Copy_to SR HRM PV
Title	TRACK ANALYSIS FILTER 771C 8/26/77		
Author	MCDOWELL, L.M.; WHICKER,	Date 01/01/78	Copy_to MC SR
Title	SIZE CHARACTERISTICS OF PLUTONIUM PARTICLES IN ROCKY FLATS SOIL		
Author	SEHMEL, G.A. , MEYER,	Date 01/01/78	Copy_to SR
Title	PLUTONIUM CONCENTRATIONS IN AIRBORNE SOIL AT ROCKY FLATS AND HANFORD DETERMINED DURING RESUSPENSION EXPERIMENTS		
Author	FEELY, H.W.	Date 01/13/78	Copy_to SR
Title	INFORMATION CONCERNING EML AIR FILTER SAMPLES FROM ROCKY FLATS PLANT SITES		
Author	WEDDING, J.B.; CARNEY,	Date 06/01/78	Copy_to SR
Title	DETERMINATION OF SAMPLING EFFECTIVENSS OF ROCKY FLATS HI-VOLUME SAMPLER AND FILTRATION EFFICIENCY OF MICROSORBAN-98 FIBER FILTER.		
Author	OLSEN, R.L.; HAYDEN,	Date 01/01/79	Copy_to SR HRM
Title	SOIL DECONTAMINATION AT ROCKY FLATS		

Rocky Database - Author/Title/Data/Copy to

Author	AGARWAL J.K. AND B.Y.H.	Date	03/01/80	Copy_to	SR
Title	A CRITERION FOR ACCURATE AEROSOL SAMPLING IN CALM AIR				
Author	LIU B.Y.H AND D.Y.H. PUI	Date	01/01/81	Copy_to	SR
Title	AEROSOL SAMPLING INLETS AND INHALABLE PARTICLES				
Author	HUNT D.C. AND J.D. HURLEY	Date	07/10/81	Copy_to	SR PARTS TO HRM
Title	HEALTH, SAFETY AND ENVIRONMENT DEPARTMENT, ENVIRONMENTAL SCIENCES BRANCH, PROGRESS REPORT FOR JANUARY-JUNE1980				
Author	WEDDING, J.G.	Date	08/01/81	Copy_to	SR
Title	WIND TUNNEL CHARACTERIZATION OF SIERRA HIGH-VOLUME SAMPLER WITH CYCLONE PRECLASSIFIER INLET				
Author	LANGER G.	Date	12/28/81	Copy_to	SR HRM
Title	DUST TRANSPORT. WINDBLOWN AND MECHANICAL RESUSPENSION				
Author	HUNT D.C.	Date	06/14/82	Copy_to	SR; IN CHEMRISK FILES, INEL
Title	ENVIRONMENTAL SCIENCES BRANCH SEMIANNUAL PROGRESS REPORT JANUARY-JUNE 1981				
Author	WALRAVEN D.J.	Date	09/01/82	Copy_to	SR
Title	HEALTH HAZARD OF PLUTONIUM ENRICHED SOIL AT ROCKY FLATS				
Author	LANGER G.	Date	01/01/83	Copy_to	SR; HRM; GGK; AR; PV
Title	ACTIVITY, SIZE, AND FLUX OF RESUSPENDED PARTICLES FROM ROCKY FLATS SOIL				
Author	HUNT D.C.	Date	04/22/83	Copy_to	IN CHEMRISK FILES, RF READING
Title	ENVIRONMENTAL SCIENCES BRANCH SEMIANNUAL PROGRESS REPORT FOR 1981. JULY THROUGH DECEMBER				
Author	RODES C.E. ET AL.	Date	04/01/85	Copy_to	SR
Title	A FIELD COMPARISON OF PM10 INLETS AT FOUR LOCATIONS				
Author	WEDDING J.B. ET AL.	Date	06/01/85	Copy_to	SR
Title	COMMENT ON "A FIELD COMPARISON OF PM10 INLETS AT FOUR LOCATIONS"				
Author	MILFORD J.B. AND C.I.	Date	12/01/85	Copy_to	SR
Title	THE SIZES OF PARTICULATE TRACE ELEMENTS IN THE ATMOSPHERE--A REVIEW				
Author	PARICIO M.L.	Date	01/01/86	Copy_to	AR SR (PARTS)
Title	A COMPARISON OF METHODS FOR DEMONSTRATING COMPLIANCE WITH 40 CFR 60 SUBPART H- THE NATIONAL EMISSIONS STANDARD FOR RADIONUCLIDE EMISSIONS FROM DEPARTMENT OF ENERGY FACILITIES- AT THE ROCKY-FLATS-PLANT.				
Author	LANGER G.	Date	01/01/86	Copy_to	CHEMRISK FILES; SR;AR;GGK
Title	MICROPHYSICS OF PLUTONIUM RESUSPENSION FROM PRAIRIE GRASS COVERED SOIL				
Author	DAY S.A.	Date	02/17/86	Copy_to	SR
Title	DETERMINATION OF TOTAL ALPHA DISINTEGRATIONS USING A 2-PI PROPORTIONAL COUNTER				
Author	LANGER G.	Date	05/01/87	Copy_to	SR
Title	EVALUATION OF PM-10 COMMERICAL INLETS FOR NEW SURVEILLANCE AIR SAMPLER				
Author	LANGER G.	Date	09/10/87	Copy_to	SR (& IN INEL-LIB)
Title	APPLICATION TECHNOLOGY PROGRESS REPORT: EVALUATION OF PM-10 COMMERCIAL INLETS DEVELOPMENT OF AN INLET FOR NEW ROCKY FLATS PLANT SURVEILLANCE AIR SAMPLER. JANUARY 1986-DECEMBER 1986				

Rocky Database - Author/Title/Date/Copy to

Author	VINCENT J.H.	**Date** 01/01/89	**Copy_to** SR PV
Title	AEROSOL SAMPLING, SCIENCE AND PRACTICE		
Author	VINCENT J.H. ET AL.	**Date** 01/01/90	**Copy_to** SR
Title	AEROSOL INHALABILITY AT HIGHER WINDSPEEDS		
Author	MROZ E.J. ET AL	**Date** 11/01/90	**Copy_to** SR
Title	ROCKY FLATS PLANT AMBIENT AIR MONITORING NETWORK: ASSESSMENT OF SAMPLING EQUIPMENT AND ANALYTICAL PROTOCOL		
Author	GARLAND J.A. AND K.W.	**Date** 01/01/91	**Copy_to** SR
Title	A REVIEW OF METHODS FOR SAMPLING LARGE AIRBORNE PARTICLES AND ASSOCIATED RADIOACTIVITY		
Author	LARSEN R.	**Date** 02/01/92	**Copy_to** SR
Title	SECTION 7.17 "AIR SAMPLING FILTERS" IN HASL PROCEDURES MANUAL		
Author	NININGER, R.C. AND B.J.	**Date** 04/23/93	**Copy_to** SR
Title	DEVELOPMENT OF AN AMBIENT AIR SAMPLER THAT SATISFIES ROCKY FLATS PLANT MONITORIN REQUIREMENTS		
Author	TERRY, R.W.	**Date** 11/03/93	**Copy_to** PV SR HRM
Title	AIR MONITORING DATA TABLES, 1992-1993		
Author	HIGLEY K.A.	**Date** 08/26/94	**Copy_to** SR HRM PV DS
Title	VERTICAL MOVEMENT OF ACTINIDE-CONTAMINATED SOIL PARTICLES		
Author	VOILLEQUE P.V.	**Date** 04/07/95	**Copy_to** RAC, HAP
Title	FILTERS USED FOR IN-PLANT AND EFFLUENT AIR SAMPLING		

Documents from ChemRisk Document Collection from Phase I;
Moved to Norlin Library at University of Colorado-Boulder

ID 193
CL AC/08/01/70/0/193
TI Plutonium in Soil Around the Rocky Flats Plant
AU Krey, P. W. and Hardy, E. P.
DT August 1, 1970
NTS 903 Pad; 57 Fire; Particle Size
CC AC; RE
TY Health and Safety Laboratory
NU HASL-235

ID 223
CL IP/03/21/73/0/223
TI Comments on AEC and Dow Chemical Company Statements Regarding Proposed Plutonium Soil Standards
AU Martell, E. A.
DT March 21, 1973
NTS Martell, E. A.; CCEI; Pu-Soil; Soil Standards; Resuspension; Particle Size; Public Relations
CC IP
TY RFEMF

ID 478
CL RE/08/00/66/0/478
TI A Plutonium Particle Size Study in Production Areas at Rocky Flats
AU Kirchner, R. A.
DT July-August 1966
CC CH
TY American Industrial Hygiene Association Journal
NU J003797

ID 689
CL RE/02/27/73/0/689
TI Particle Size Analysis - Sample Taken from Size Reduction Area Building 776
AU Hayden, J. A.; Baker, H. M.
CC RE
NU 60-13282-RR-061
$
ID 690
CL RE/12/22/76/0/690
TI Particle Size Analyses, Smear Samples 776 Building (11-6-76)
AU Hayden, J. A.
DT December 22, 1976
CC RE

NU 60-13212-RR-010
$
ID 691
CL RE/11/02/76/0/691
TI Particle Size Analyses, Filters from 707 Building October 2, 1976
AU Hayden, J. A.; Fraser, J. K.; Murri, R. L.
DT November 2, 1976
NTS Airborne Effluents
CC RE
TY 60-13212-RR-009
NU 00005380
$
ID 758
CL IN/03/23/70/0/758
TI Letter to Mr. H. W. Church Regarding CCEI Report
AU Lee, W. H.
DT March 23, 1970
NTS Particle Size (Mishima)
; 1969 Fire
CC IN
; EN
NU J003524
$
ID 776
CL RE/11/00/79/0/776
TI Plutonium and Beryllium Plenum Filter Loading Estimates for Accidental Stack Release Calculations
AU Langer, G.
DT November 1979
NTS Beryllium; Emergency Response; Filter Efficiency; Filter Fires; Filter Plenum Inventory; Plutonium
CC RE
NU ES-376-80-213
$
ID 875
CL RE/00/00/64/0/875
TI Plutonium Aerosol Particle Size Distribution in Room Air
AU Andersen, B. V.
DT 1964
CC Re
TY Health Physics Pergamon Press
NU Volume 10, pp. 899-907
$
ID 1033
CL RE/00/00/00/0/1033
TI Filter Efficiency Studies RFP-3650
AU Langer, G.

DT Unknown
NTS Airborne Effluents
CC RE
$
ID 1074
CL EN/10/00/71/0/1074
TI The Size Distribution and Plutonium Concentration of Particles from the Rocky Flats Area
AU Nathans, M. W.; Holland, W. D.; Shaw, H. C.
DT October 1971
NTS Particle Size; Soil Particle Size; Resuspension
CC EN; MO
NU 0007779
$
ID 1092
CL RE/05/17/74/0/1092
TI Particle Size Analysis, Building 771 Effluent Air; Environmental Studies Service Report
AU Hayden, J. A.
DT May 17, 1974
NTS Airborne
CC RE
NU 00005382
$
ID 1094
CL RE/11/29/72/0/1094
TI Particle Size Analysis - 776 Building Effluent Air
; Product and Health Physics Research Service Report
AU Hayden, J. A.
DT November 29, 1972
NTS Airborne Effluents
CC RE
NU 00005386
$
ID 1095
CL RE/07/17/72/0/1095
TI Particle Size Analysis - PuO2 in Building 776 Effluent Air Using the Fission Track Method; Product and Health Physics Research Service Report
AU Hayden, J. A.
DT July 17, 1972
NTS Airborne Effluents
CC RE
NU 00005387
$
ID 1096
CL RE/00/00/61/0/1096
TI Particle Size Studies on Plutonium Aerosols
AU Moss, W. D.; Hyatt, E. C.; Schulte, H. F.

DT 1961
NTS Airborne Effluents; Particulates
CC RE
TY Health Physics
NU Volume 5, pp. 212-218
$
ID 1121
CL EN/01/15/79/0/1121
TI Waste Management of Actinide Contaminated Soil (Internal Report - Not Cleared for Publication)
AU Navratil, J. D.; Thompson, G. H.; Kochen, R. L.
DT January 15, 1979
NTS Particle Size Studies
CC EN
TY CRD79-016
$
ID 1167
CL AC/00/00/78/0/1167
TI Determination of Sampling Effectiveness of Rocky Flats High-Vol Sampler
AU Wedding, James B.
DT 1978
NTS Efficiency Air Sampling
CC AC
$
ID 1171
CL MO/00/00/76/0/1171
TI Resuspension of Plutonium: It's Particle Size Distribution in Soil
AU Unknown
DT 1976
CC MO
$
ID 1175
CL RE/02/20/70/0/1175
TI Status Report on Plutonium Particle Study
AU Woodard, R. W.; Bramlet, H. L.; Nau, R. J.; Peck, D. M.
DT February 20, 1970
NTS Exhaust Duct; 1969 Fire; Cascade Impactors; Filter Efficiency
CC RE
$
ID 1178
CL RE/07/00/74/0/1178
TI Plutonium Aerosol Size Characteristics
AU Elder, J. C.; Gonzales, M.; Ettinger, H. J.
DT July 1974
NTS Plutonium; Particle Size; Building 707; Building 771; HEPA Filters
CC RE

TY Health Physics Pergamon Press
NU Vol. 27 (July), pp. 45-53
$
ID 1197
CL RE/06/25/84/0/1197
TI Health, Safety and Environmental Sciences Semiannual Progress Report for
1982 January - July, Rocky Flats Report 3650
; Quality Assurance - Filter Efficiency Studies
AU Hunt, Douglas C.
; Campbell, George W.
DT June 25, 1984
NTS Filter Effluents
CC RE
TY RFP-3650
$
ID 1223
CL EN/06/14/82/0/1223
TI Environmental Sciences Branch Semiannual Progress Report, January-June 1981 (RFR-3325)
AU Hunt, Douglas C.
DT June 14, 1982
NTS modelling; resuspension; ecology; radioecology; filter efficiency; dust-transport; dispersion modelling
CC EN
NU RFP-3325
$
ID 1247
CL RE/11/00/92/0/1247
TI Determination of Particle Size Distribution and Composition of the Effluent Air Emissions from Building 559
AU Nininger, R. C.; Osborne, W. E.
DT November 1992
DE Attachment 1
CC RE
TY 93-RF-2657
$

ID 1254
CL RE/00/00/63/0/1254
TI Collection Efficiency of Whatman 41 Filter Paper for Submicron Aerosols
AU Lindeken, C. L.; Morgin, R. L.; Petrock, K. F.
DT 1963
NTS collection efficiency
CC RE
TY Health Physics Pergamon Press
NU Vol. 9, pp. 305-308
$

ID 1256
CL RE/00/00/64/0/1256
TI Surface collection Efficiency of Large-Pore Membrane Filters
AU Lindeken, C. L.; Petrock, F. K.; Phillips, W. A.; Taylor, R. D.
DT 1964
NTS filter efficiency
CC RE
TY Health Physics Pergamon Press
NU Vol. 10, pp. 495-499
$
ID 1258
CL RE/12/24/86/0/1258
TI Ambient Air Quality in Uranium Production Areas
STI HS&E Application Technology Semiannual Progress Report January 1985 Through June 1985
AU Langer, G.
DT December 24, 1986
NTS filter efficiency; Whatman 41; Uranium
CC RE
TY RFP-3990
$
ID 1271
CL RE/11/00/92/0/1271
TI Determination of Particle Size Distribution and Composition of the Effluent Air Emissions from Building 559
AU Nininger, R. C.; Osborne, W. E.
DT November 1992
CC RE
TY 93-RF-2657
$
ID 1286
CL EN/10/11/73/0/1286
TI Analysis of Outdoor Soil by Fission Track Methods
AU Hayden, J. A.
DT October 11, 1973
NTS particle size; plutonium; distribution; soil particles
CC EN; MO
NU 00006381
$
ID 1287
CL EN/09/24/74/0/1287
TI Letter to Phil Krey Regarding the Particle Size of Plutonium in the Rocky Flats Soil
AU Hayden, J. A.
DT September 24, 1974
NTS particle size; plutonium; soil; distribution
CC EN; MO
NU 00006416

$
ID 1289
CL RE/02/09/72/0/1289
TI Analysis of Particles Collected Near the Incinerator During a Contamination Incident
AU Hayden, J. A.
DT February 9, 1972
NTS incinerator; particle size; electron microscope; fission tracks
CC RE; IN
NU 00006783
$
ID 1290
CL EN/06/04/76/0/1290
TI Telephone Call Between Tamura and Hayden Regarding Tamura's Results on Association of Plutonium with Particular Particle Size of Soil at Rocky Flats
AU Hayden, J. A.
DT June 4, 1976
NTS particle size; soil; plutonium; distribution; Carl Johnson
CC EN; MO
NU 0007799
$
ID 1291
CL EN/03/30/76/0/1291
TI Analyses of Wind-Blown Soil from Plowed Field in the Buffer Zone - February Samples
AU Hayden, J. A.; Bokowski, D. L.; Froser, J. K.
DT March 30, 1976
NTS particle size; plutonium; resuspension; soil
CC EN; MO
NU 00006372
$
ID 1309
CL EN/01/21/81/0/1309
TI Environmental Studies Group Progress Report for 1979
AU Hunt, D. C.
; Hurley, J. D.
DT January 21, 1981
NTS collection efficiency; sediment sampling; soil sampling; resuspension; emission rates; epidemiology; exposure pathways; filter media
CC EN
TY RFP-3115